NEXT100 Energy Plane Status

Derek Shuman, Dave Nygren, Azriel Goldschmidt, Tom Miller
NEXT Collaboration
Lawrence Berkeley National Laboratory (LBNL), Berkeley CA, USA

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Contents

1 Introduction

The Energy Plane (PMT's, enclosures and support system) is designed to:

- Position the energy plane PMTs inside the detector for best light collection,
- Protect them from the high pressure xenon,
- Avoid a chain reaction multiple PMT implosion event, in case of window fracture,
- Provide the PMT signal and power interfacing,
- Be as radiopure as reasonably possible,
- Accommodate a movable radioactive source for calibration.

The Energy head system is shown in fig. 1.

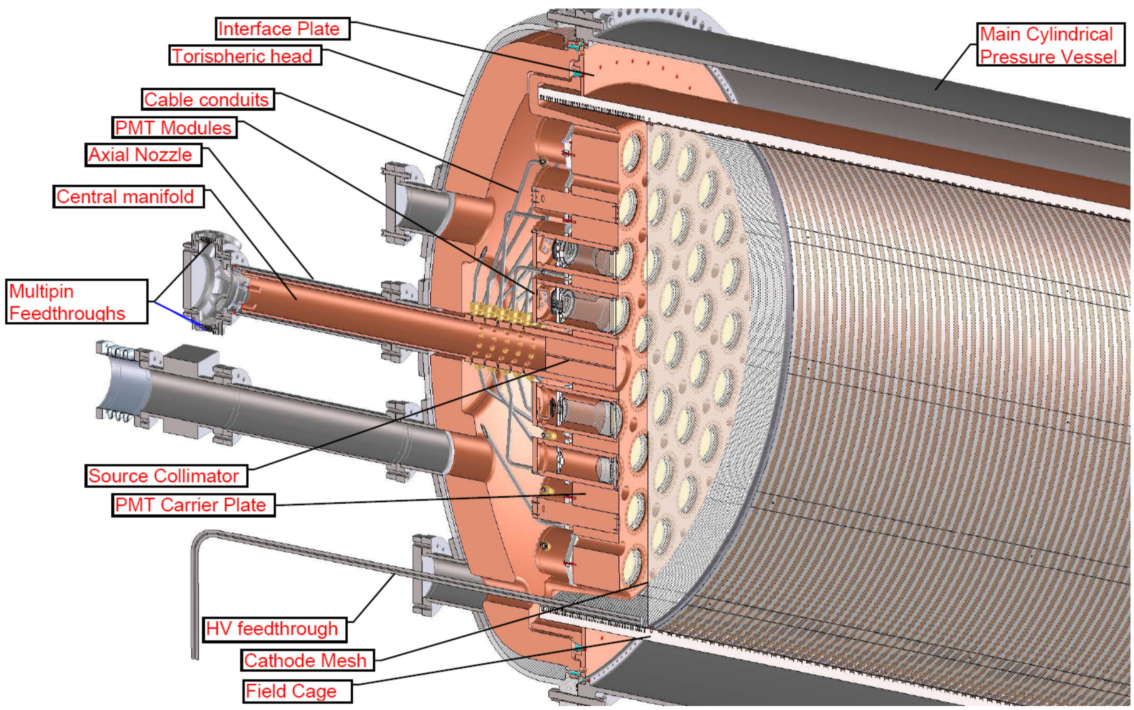

Figure 1: PMT Module

2 Description

The energy plane is based on a modular approach, to minimize development risk and cost.
A brief system overview is as follows:

- PMTs are sealed into individual pressure resistant, vacuum tight, radiopure OFE tubular copper enclosures with sapphire windows, forming a PMT Module. A vacuum of $10^{-}4$torr or better is maintained inside.
- The PMT modules are all mounted onto a single OFE copper carrier plate that attaches to the internal copper shielding bars (ICS) lining the main cylindrical vessel.

- Sapphire windows are clamped by copper flanges to the front end of the enclosure, sealing with an O-ring, or a metal C-ring. A similar backplate of copper seals the back side of the enclosure.

- The PMT is optically coupled to the sapphire window backside via a silicone optical pad; springs are used to provide contact force.

- The sapphire window is coated with conductive indium tin-oxide (ITO) on the entire front surface, to prevent electric field penetration from the cathode mesh, this is overcoated with tetraphenyl butadiene (TPB) wavelength shifter, over the exposed window surface, to shift VUV light to blue. Electrical connection of the ITO to the enclosure is made by using a conductive polyethylene (UHMWPE) pressure ring, between the copper flange and the window.

- PMT bases are potted with heat conducting (electrically insulating) epoxy to flexible copper cables which then connect to the enclosure backplate (direct cooling by conduction is needed in vacuum)

- PMT cables are enclosed in individual pressure resistant, vacuum tight tubing conduits of copper or stainless steel which attach to each enclosure using a compression fitting. This fitting attaches to the enclosure with pipe threads, epoxied with Torr-seal.

- Cable conduits all lead to a central manifold fabricated from copper pipe, connecting with a compression fitting (also pipe thread w/Torr-seal).

- PMT cables route through central manifold to 41 pin CF feedthroughs mounted on a CF stainless steel octagonal vacuum chamber (octagon), outside the lead shielding.

- High vacuum($p < 10^{-6}$ torr) is applied at one octagon port; good vacuum ($p < 10^{-4}$ torr) is maintained inside enclosures through conduits, well below Paschen minimum, avoiding sparkover or glow discharge across PMT pins.

- Vacuum source is a (continuously pumped) large vacuum tank of 20-30m^3; in case of sapphire window failure, this limits pressure buildup in central manifold, avoiding a Super-K chain reaction implosion scenario. It also retains EXe, as a fast vacuum gate valve is installed on the opposite side of the vacuum tank. Xenon permeation through seals is recovered with a cold trap inside the tank, ahead of the vacuum pump.

- PMT Modules are clamped into copper heat conduction flanges attached to the copper carrier plate.

- Heat is carried to pressure vessel flange by conduction through copper carrier plate; 5 C total temp rise.

- PMT is operated in +HV mode with photocathodes grounded; using a Zener diode stabilized differential mode between anode and last dynode, from D. Nygren.

The PMT module is shown in fig. 2.

This design requires a vacuum inside the enclosure, so as to detect the presence of any Xe leakage. Without vacuum, the enclosure would eventually pressurize and destroy the PMT. Xenon leakage through seals will be recovered in a cold trap in the vacuum system. The primary

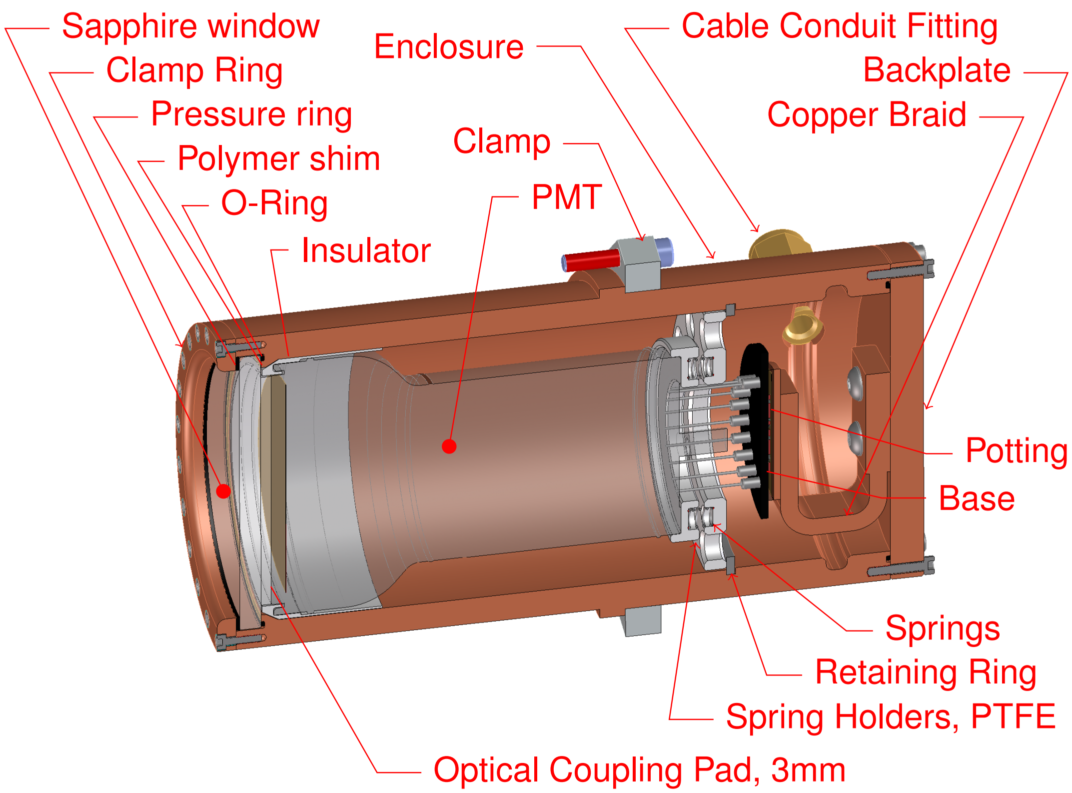

Figure 2: PMT Module

concern with vacuum is possible flashover across the PMT pins; this is avoided by maintaining enough conductance through each conduit (with cable inside) in conjunction with a high vacuum in the central manifold to keep enclosure pressure several orders of magnitude below the Paschen minimum (for Xe).

2.1 PMTs and Bases

PMT's are Hamamatsu R11410-10 low background with good response at 175nm as well as at longer wavelengths. The PMT is shown in fig. **??**.

Typical quantum efficiencies, as measured, from [1] are in shown in fig 4:

These PMTs require up to 1750V for operation. They can only withstand 2 barg external pressure, and so may not be exposed to pressurized xenon. The PMTs may be operated with the photocathode at -1500 V, or at ground, with anode at +1500V. Since the PMT metal body is at the same voltage as the photocathode, we plan to operate in +HV mode. This avoids HV insulating the PMTs from their enclosures (they will be insulated even for +HV operation to avoid ground loops), or floating the entire PMT carrier assembly at -1500 V inside the vessel. However, we have designed and fabricated a prototype insulator from polyetherimide (PEI, Ultem-1000) that may be sufficient to provide PMT insulation inside the enclosure, should this be desired.

The proposed PMT operation scheme, by D. Nygren, is to use a semi-differential signal between the anode and the last dynode. Figure 5 shows the initial base design for an assumed average output current of 160 nA .

The external box containing the zener diode is shown in fig. 6.

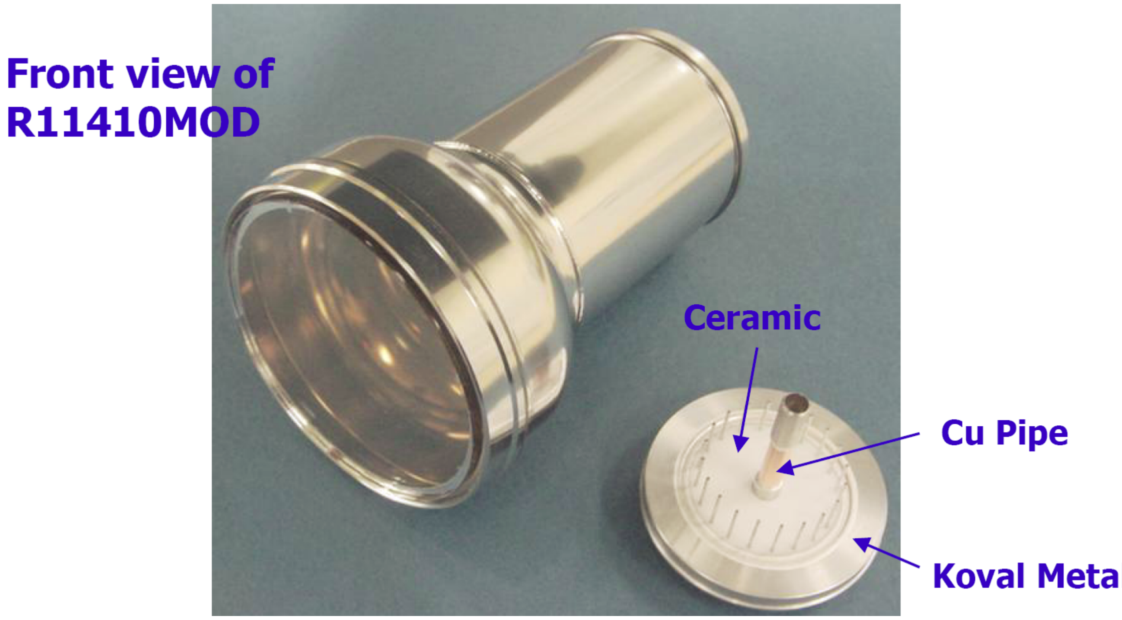

Figure 3: Hamamatsu R11410-10 3" PMT

This base design dissipates 0.9W of power inside the enclosure.

The PMT bases will be designed to be soldered to the pins, after shortening them. Resistors are Finechem SM5 surface mount type, which have been measured for radiopurity and found acceptable. All resistors are mounted to the backside of the base, while capacitors will be mounted on the front side, between the PMT pins. A copper heatsink plate will be bonded to the resistors using a thin layer of kapton with thermally conductive, electrically insulating epoxy on both sides. A short section of braided copper cable (grounding strap) is soldered to this plate, and the other end attaches to the enclosure backplate with 4 screws. PMT resistor heat is then dissipated through direct thermal conduction into the enclosures, proceeding out through the clamps and carrier plate to both the pressure vessel flange and into the circulating xenon. Estimated total temperature rise at this power is 5C. Estimated gas temperature rise is 1C

The PMT body needs to be electrically insulated from the enclosure, even for +HV operation, where both the body and the enclosure are at ground; this is to avoid ground loops. An Ultem-1000 insulator (polyetherimide) prototype has been designed and fabricated which may be sufficient to insulate the body even for -HV operation. Its radiopurity is unknown; the material is similar to Kapton (polyimide), tests are planned. Alternatively, an insulating coating of epoxy or polyurethane can be applied to the widest section of the PMT body, spin curing to form a uniform film. There may be sleeving for this purpose as well (no heat shrink!).

2.2 Enclosures

The enclosures are fabricated from OFE (OFHC) extra heavy wall copper pipe; they have a sapphire window on one end, and a simple copper backplate on the other end. The sapphire window and backplate are sealed to the enclosure using O-rings, or if feasible, Helicoflex metal C-rings. The enclosure incorporates a beveled ledge for the window to bear against. The ends of the enclosure are tapped and a clamp ring is used to apply the sealing force though a polymer pressure ring. Fig. 7 shows a detail of the seal design for the window. A Kapton shim of 0.1mm thickness is used to reduce localized stress by avoiding metal on sapphire contact; this shim cannot

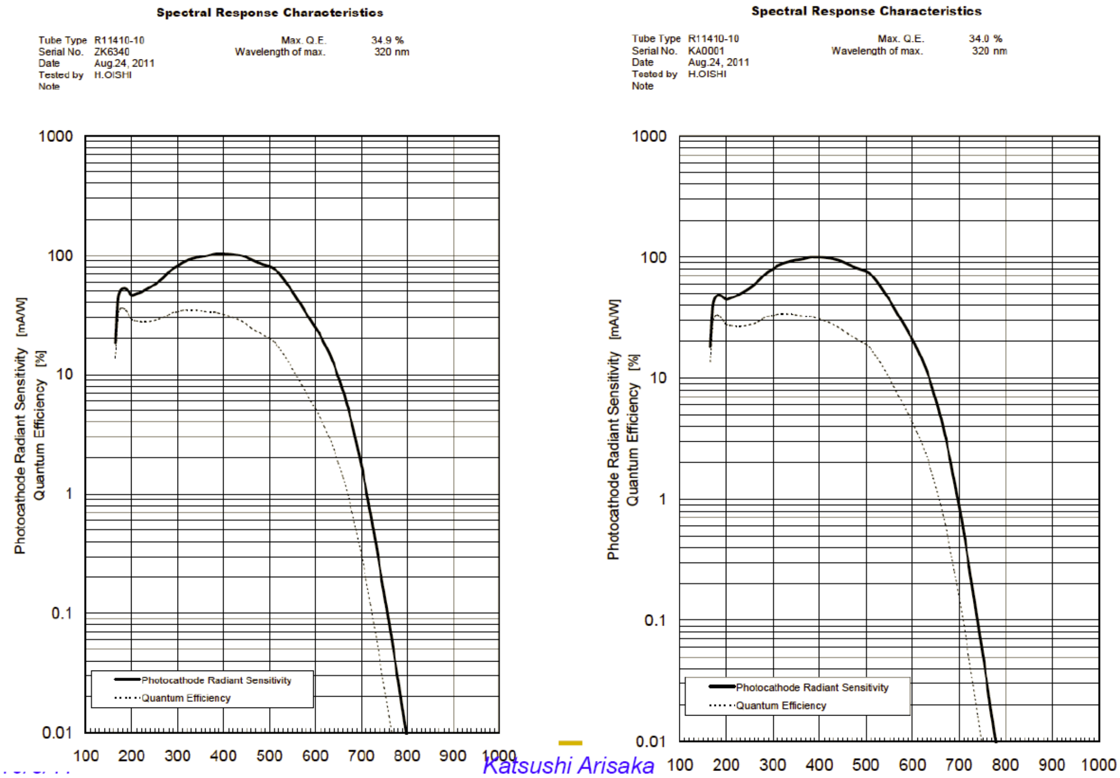

Figure 4: Quantum efficiency, R11410-10, as measured

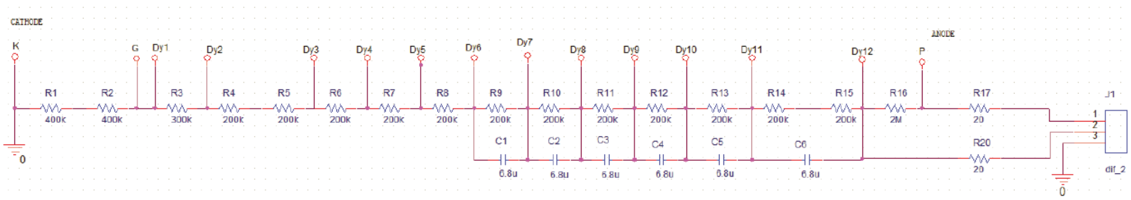

Figure 5: Base Schematic

be too thick otherwise the O-ring may extrude into the gap between the window and the ledge.

This design attempts to produce a quasi fixed-edge condition for the window, rather than a freely rotating simple edge support condition. Doing so reduces maximum window stress, gaining additional factor of safety. A fully fixed edge condition is not truly possible without bonding the window to the enclosure.

Leakage through O-rings (total for 60 enclosures) is calculated to be no more than 300 gm/yr, which will be recovered using a cold trap in the vacuum system. As an option, tests are underway to see if a Helicoflex metal gasket (C-ring) can seal against the sapphire without damage; if so, a lower leak rate may be advantageous. Vacuum of p¡ 50 millitorr is estimated to be a minimum requirement to prevent flashover on PMT pins; one order of magnitude better is estimated to be achievable, pumping through a 4.4 mm ID line with a 2.4 cable 0.5m long. Initial testing has begun, in air, and a vacuum of 1.2 millitorr has been achieved. Tests at 15 atm external pressure (Ar), and using larger cable conduits are planned.

The copper pipe wall thickness is left as thick as possible, 1 cm, so as to provide shielding; this is far in excess of that required for pressure resistance. Lot samples of the copper pipe will be checked for radiopurity prior to purchase for full fabrication.

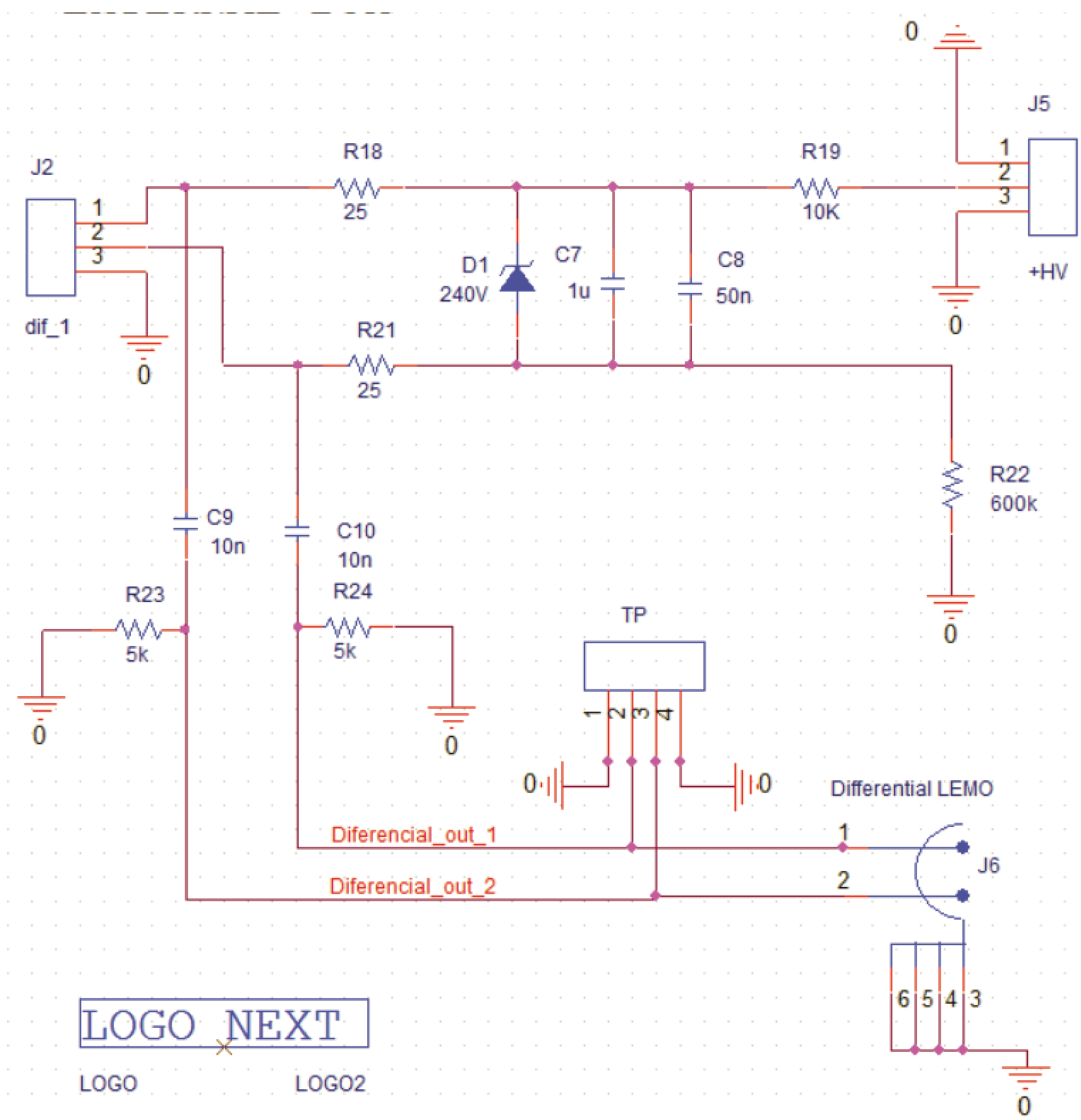

Figure 6: External Interface Box Schematic

The windows are inserted from the front side and the PMT is inserted from the backside. This is required in order to use pipe, as there is an internal flange for the window to bear against, containing the O ring groove. The alternative is to make the enclosure and window larger in diameter, which is undesirable.

The PMT is optically coupled to the window backside using silicone optical pads of 3mm thickness; use of grease is not advisable since any type of grit between the window and the PMT face can scratch the window where tensile stress from pressure is highest, leading to premature window failure (see window section below).

The PMT is held against the optical pad by a spring assembly on the backside; the springs are mounted in PTFE or UHMWPE interface collars. One collar bears against a retaining ring held in a groove machined into the ID of the enclosure and the other collar bears against the rear edge of the PMT, per Hamamatsu's recommendation. Thus the PMT can be installed independently from the window. If the base is not soldered to the pins (using spring connectors only) the base

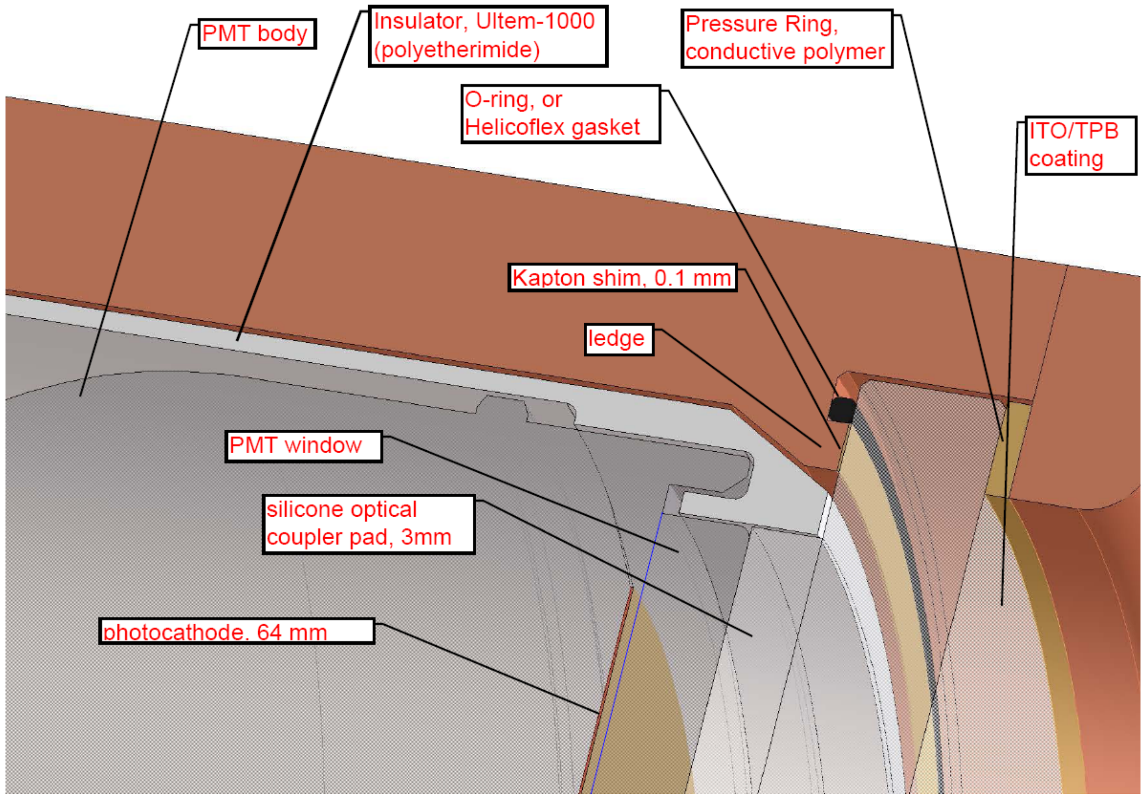

Figure 7: Detail, Window Seal

can be serviced or replaced without disturbing the optical coupling of the PMT to the window.

Cables from the base exit through a vacuum tight compression tube fitting into a copper tube that serves as both a cable conduit and a vacuum port for the interior. The enclosure has sufficient wall thickness to be tapped for 1/4 in. pipe threads, thus the tube fittings can be screwed in, using Torr-seal high vacuum compatible epoxy for a thread sealant. Locating these fitting on the side of the enclosure allows the back cap to be removed for PMT and base access without disturbing the conduit fitting. The fittings are straight, so as to allow a larger bend radius in the conduit, however a 45 deg. fitting may be feasible. 90 degree fittings likely have too small a bend radius for the cable.

2.3 Sapphire Windows

The sapphire windows will first be coated on one side with indium tin oxide (ITO) to form a transparent (410nm and above) conductive coating. The conductivity is required to prevent electric field penetration into the PMT. The entire front surface will be coated so as to make electrical contact. Over this coating a layer of TPB is evaporated, at the smaller, exposed diameter which will shift any direct light (EL or S1) to a wavelength that has high transmission through the sapphire window and the optical coupling pad. This coated side faces outward, and electrical contact of the ITO layer to the antirotation washer is provided by using a carbon filled UHMWPE pressure ring. Alternatively, instead of ITO, a transparent mesh screen may be used (over a window coated only with TPB), this screen located between the pressure ring and window clamp ring.

2.3.1 Window Strength and Reliability

Sapphire is chosen over other possible materials such as Suprasil synthetic quartz, due to its much higher strength; this allows a reasonable window thickness of several mm which improves light acceptance. Finished window cost is lower than Suprasil for equivalent strength and finish. Radiopurity is at present known only be < 10 mBq/kg (U), < 1 mBq/kg (Th), however .

Window reliability against breakage is assured by following a two step method:

- Determine a test pressure to assure that any window that does not break when tested, will not break in long term service, then:

- Pressure test all windows, both sides, using oil, not water, at an appropriate test pressure

One can find typical strength (flexural) numbers of 500-700 MPa for sapphire in manufacturer's literature, however, sapphire, like other brittle materials, has an actual strength that is not only a function of the intrinsic material strength, but also a strong function of the flaw content present (unlike ductile materials, like metals, where intrinsic material strength is the primary determinant of actual strength). For windows stressed in bending, where maximum tensile stress is highest at the surface, surface flaws are more important than internal flaws, and the degree of polish has a strong effect on strength. Large windows show a reduced strength compared to smaller equivalents, since the chance of having a critical size flaw present goes up with increased (stressed) area. Crack growth is the failure mechanism, as no ductility is present which can act to blunt the crack tip. In ductile materials like metals, cracks primarily grow from cyclic stresses, but in ceramics, crack growth is primarily caused by the phenomenon of stress corrosion cracking wherein the presence of moisture, in conjunction with high stresses at the crack tip act to dissociate the atomic bonds, and cyclic stresses do not seem to have a significant effect [4]. The degree of polishing, and the size of the window, affect the resulting strength to a significant degree, as crack growth rates are a function of initial flaw sizes. Typically, the crack growth rate is slow until a critical size is reached (at the given stress level), then growth rate accelerates quickly to failure. This crack growth phenomenon is quantified using the methods of linear elastic fracture mechanics (LEFM).

First we use LEFM to determining a test-to-actual pressure ratio that will assure that any window which survives the test pressure for a short time, will not contain a flaw large enough to grow at a rate that will lead to failure at the operating pressure after a long time (10 years or more). We use published parameters of [4] In the Appendix to determine a test/operating pressure ratio of 1.6. Before We still need to determine an appropriate stress level for our window. This is done by using the methodology of Weibull distributions.

The Weibull distribution [2], gives the probability of failure as a function of applied stress and stressed area for brittle materials, and single crystal sapphire has been shown to follow this distribution reasonably well , [3]. We use the published parameters of [3] to determine a thickness whereby 95% of all windows purchased will not fail at the test pressure. We choose this initial survival probability as a balance between excessive breakage during testing and excessive window thickness. We do not have a strong requirement to minimize thickness for optical transmission, and window cost is dominated by polishing, not material cost. We gain further reliability by specifying a finer polish (20/10) than the typical (60/40) scratch/dig which was used as the basis of the published Weibull parameters. Calculations indicate a thickness of 4.9mm is required to achieve this 95% testing survival rate. Prototype windows have been ordered at 5mm thickness. For added margin we are designing to use 6mm thick windows.

The O-ring requires a groove to seal correctly and a lip is provided on the enclosure ID for this purpose. As such, the window bears against this lip from both pressure and from pressure ring forces. To avoid high stress concentration at the edge of the (metal) lip, a polyimide (Kapton) or PEEK shim of 0.1 mm thickness is placed between the window and the lip. Thus no metal contact with the window occurs on either face. However, tests are underway at IFIC to see if a metal Helicoflex gasket can be used.

2.3.2 Window Radiopurity

The 3 prototype windows (UV grade) have been measured at LBNL to an upper limit of 10 mBq/kg (U), 1 mBq/kg (Th). We would like to measure to a level 2 orders of magnitude less, but will need at least 10x larger sample to do so. Efforts are underway to work with manufacturers to submit precut blanks or even the raw boule for acceptance testing prior to purchase, however this has been unsuccessful so far. We estimate using numbers for Czochralski grown boules in the ILIAS database

2.4 Conduits and Cables

Conduits are either copper tubing or stainless steel, screened for radiopurity. Nominal OD is 1/4" (6.35mm) wall thickness of .031" (0.75mm). This is sized to give a clearance to the PMT triaxial cable which will provide an acceptable pumping speed, so as to maintain good vacuum inside the enclosure. 5/16" or 3/8" OD tubing with .031" wall thickness is also feasible, and would give better gas conductance, if needed; both will be tested.

There are two failure modes for external pressure, buckling, and elastic limit. At 15 bar external pressure a wall thickness of only .005" is required to avoid collapse, safety factor goes as the cube of the thickness. Where the conduit is bent to an arc, it will deform to an ellipsoidal shape (keystoning). The tube will collapse if yield stress is exceeded. For a maximum aspect ratio of 0.8 (D_{min}/D_{maj}) maximum stress is 20 MPa, well below the yield strength of 1/4 hard OFHC (180 MPa). Care must be taken to use proper bending tools and procedures.

The PMT cable is a copper conductor, Kapton insulated triaxial UHV compatible cable available from Accu-glass Products, Inc., in California, with 26 or 28 gauge center conductor and an OD of 2.5 or 3mm.

The fittings can be a flare fitting, VCR, or Swagelok; testing will be performed to determine the most reliable fitting type. Conduit layout is shown in figs. 8 and 9.

Conduits will be pre-bent in fixtures with cables preinstalled, however the large bend radii allow cables to be fed through after bending.

Vacuum testing of conduits has been started, the initial set up is shown in the photo 10. The isolation valve allows using the same vacuum gauge (cold cathode) for both supply and sensing pressure.

A pressure vessel has been designed and built to simulate the high external pressure the enclosures will see in actual use, Permeation though O-rings will be tested using this chamber. Fig. 11 shows a cross section.

2.5 Carrier Plate

The PMT module carrier plate is a convoluted circular plate of copper to which the modules are attached. It attaches to the ends of the internal copper shielding bars (ICS) that are themselves attached to an internal flange inside the main cylindrical vessel. The torispheric head has only a

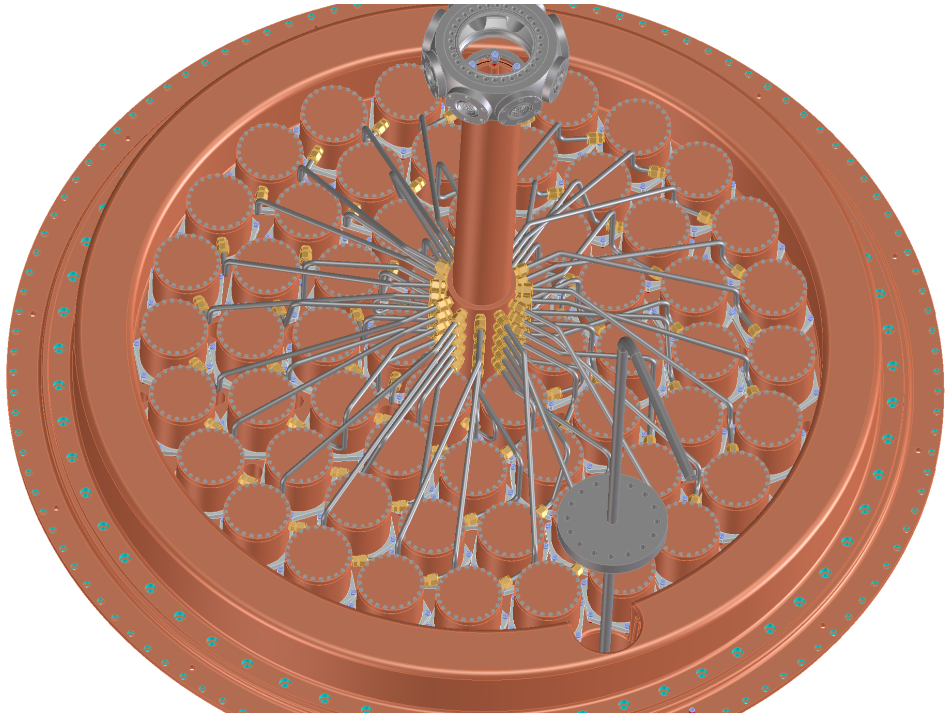

Figure 8: Energy Plane

copper shield disk (part of ICS) fastened to its inside flange. The carrier plate is fabricated from a thick 20 cm copper plate or casting so as to provide additional shielding and to displace EXe. It serves to carry PMT heat to the pressure vessel flange. Cooling may be applied to the outside of the vessel flange, if desired.

The current location of the high voltage feedthrough maximizes its distance to the carrier plate, but precludes the use of a single large ground mesh covering the entire energy plane. Thus, the sharp edges and bolts of the window clamp ring are part of the ground plane and could be prone to sparking or perhaps local light production. A test is planned to simulate the electric field in this area, by fabricating a section of the carrier plate surrounding the enclosures, then using Ar@1 atm as a test gas, scaling results accordingly. We will use our 20 kV power supply and design for this equipotential. Somewhat more difficult to test is the periphery of the carrier plate; electrostatic field modeling (2D axisymmetric) will allow us to find the 20 kV equipotential around the carrier plate, which can then be used to fabricate a cathode simulator. This can be easily scaled to the single enclosure/carrier plate prototype.

2.6 Central manifold

The central manifold comprises two sections of pipe, a conduit manifold section and a nozzle connection section; these two sections connected by a bellows type expansion joint section (not yet designed) in the middle. This allows the conduit manifold section to be rigidly attached to the carrier plate, and the nozzle connection section to attach to the axial nozzle flange of the torispheric head without high stresses being transmitted to the nozzle. The conduit manifold section will contain, in addition to the cables, a calibration source and perhaps a collimator, located centrally in the manifold section. The conduit manifold section is currently an OFHC copper pipe (same as that for enclosures) with threaded holes for conduit fittings. As on the enclosures, Torr-seal vacuum grade adhesive will be used for the fitting pipe threads.

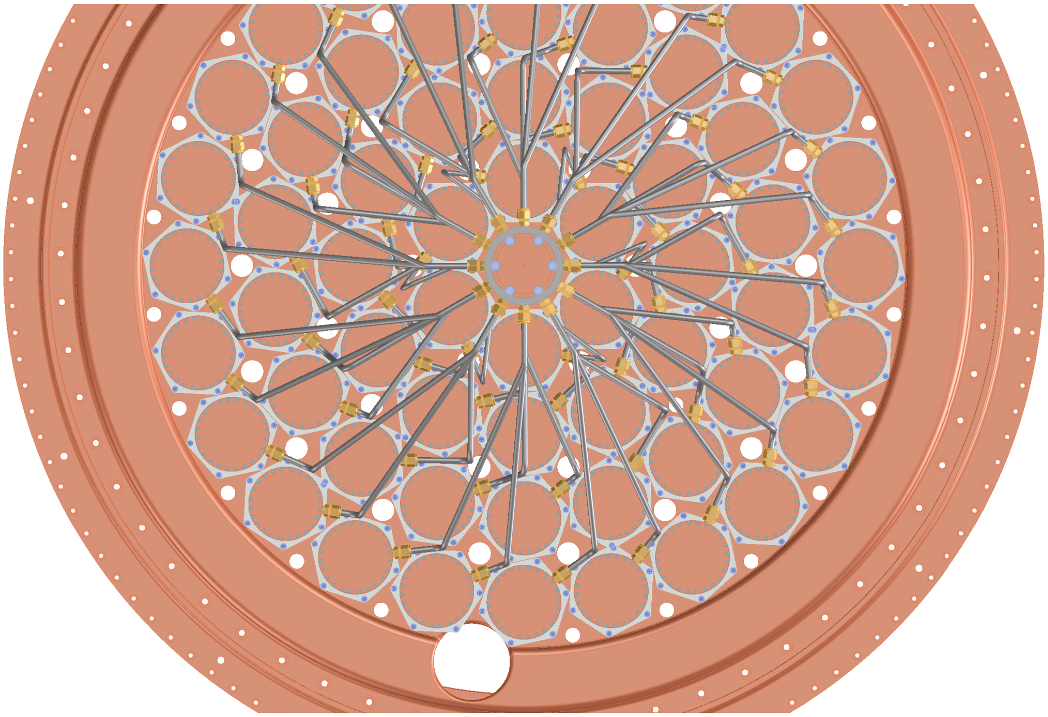

Figure 9: Energy Plane top view

2.7 Vacuum System

The vacuum system is designed to both provide a sufficient vacuum for maintaining flashover protection within the enclosures and to provide an emergency exit path for high pressure gas, should a window break, thus limiting pressure exposure of the other PMT's. In case of a sudden gas leak, flashover could occur on all PMT's, causing damage, so an electrical interlock to a fast response vacuum gauge located in the central manifold is required. Fig. 12 shows a proposed flow diagram including the vacuum tank.

The vacuum port to the large vacuum tank will be a high conductance line connecting into the octagon. In case of window failure, sudden pressure rise on the vacuum gauge and/or sudden anomalous pressure loss in the main pressure vessel will act to open the remotely operable pressure relief valve (or a solenoid valve) valve, venting the main pressure vessel contents into the vacuum tank. This tank is sized so as to arrive at a 1 bara maximum final pressure. This limits EXe loss in case of a main pressure vessel leak. It will also slow the flow of EXe into the central manifold in case of a window failure.

Upon sudden pressure rise in the vacuum tank, the fast vacuum (VAT) valve on the vacuum pump closes , limiting EXe loss to the atmosphere. The cold trap operates continuously during operation so as to scavenge EXe that has permeated into the vacuum system; during normal operation, this will periodically need to be boiled off by closing the fast valve and shutting off the pump for some period of time.

2.8 Feedthroughs

These are 41 pin MIL-C-26482 UHV feedthroughs on CF (DN40) flanges made by VACOM, in Germany. We need 3 pins per PMT, so 5 feedthroughs are needed, leaving 3 extra DN40 ports for vacuum or other purpose. These feedthroughs are pressure rated to 21 bar pressure, however they

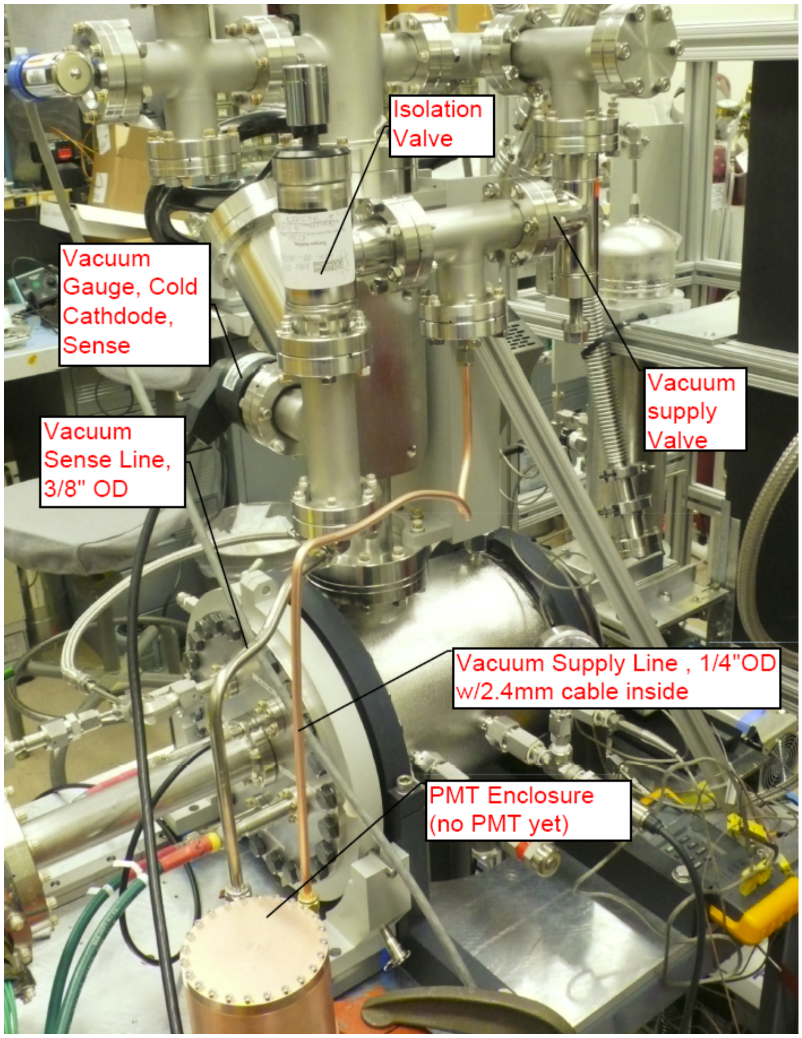

Figure 10: Conduit Vacuum Test, initial

will not see more than 1-2 barg pressure in case of window failure, due to the low conductance vacuum port leading to the large emergency vent tank, which is always open. The pin-to-pin, and pin-to-ground rated voltage rating is 1000 V for vacuum (p¡5 millitorr for equiv. Ceramtec) and air sides, however, preliminary tests on a similar 32 pin feedthrough from Ceramtec showed that at least 1500 V on all pins can be withstood when vacuum is better than 0.5 millitorr. This test was terminated at 1500V to allow more testing to be done at higher pressures, (which have been difficult to achieve, so far). Initial testing included a fully cabled air-side plug, but pins in vacuum side were bare. More and better testing is planned which will include realistic connections of triax cables to the vacuum side pins.

3 Handling and Assembly

The Carrier Plate, with PMT Modules and Central Manifold is bolted to the Interface Plate. to handle the Carrier Plate, a support fixture called a "hexapod" also known as 6-strut kinematic mount is used. The hexapod does double duty for removing the head/shield assemblies.The hexapod provides for precision rotation and translation of either the head or energy plane system so as to allow a precise mating of these components to the pressure vessel for subsequent fastening.

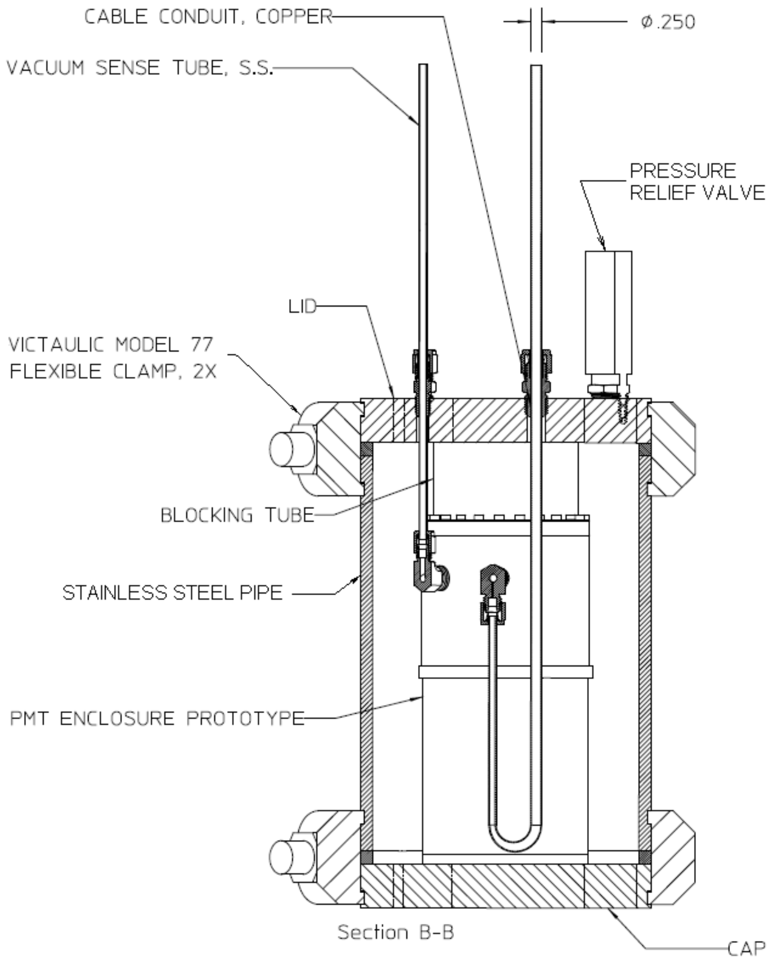

Figure 11: Enclosure Test Pressure Vessel

Figs. 13, 14,15,16,17 show the sequence of head removal, then energy plane removal and rotation to place the windows either up or down, as needed. A rotational interface fixture between the cradle support of the hexapod and the carrier plate is not shown and needs to be designed.

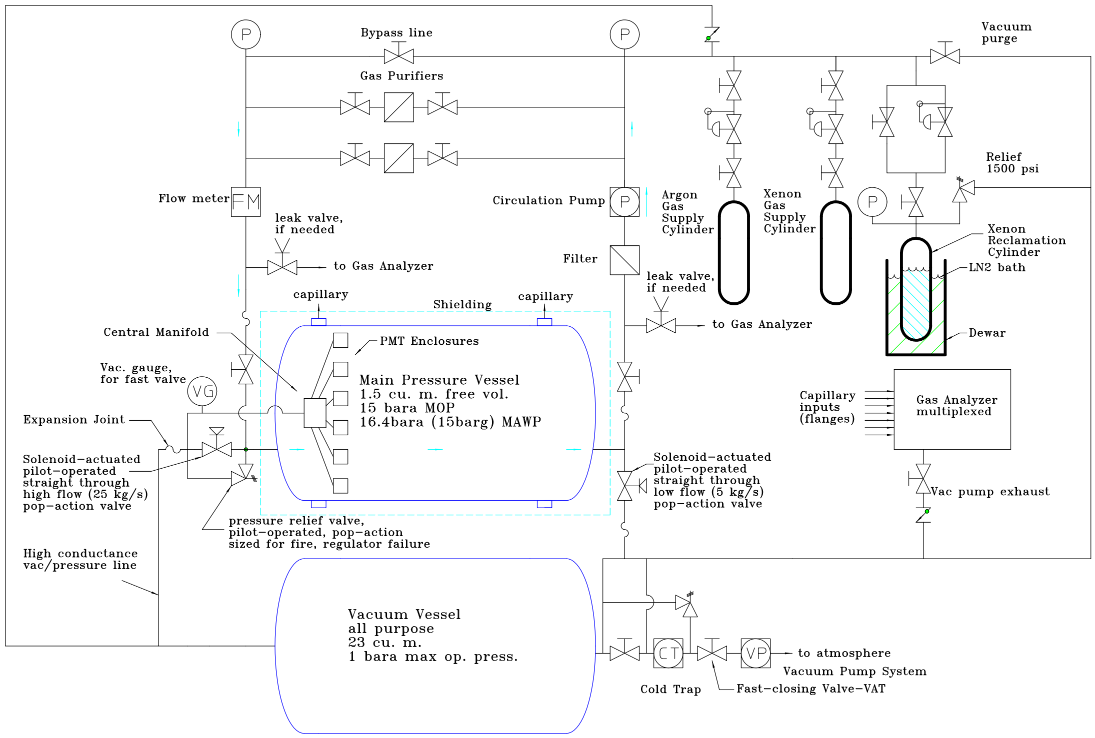

Figure 12: Gas/Vacuum System Proposal

4 Radiopurity, System

The energy plane system has an estimated activity shown in Table 1. Activities are primarily from the ILIAS database, with some from EXO, and other sources; some unknowns are guesses. No distinction is made here for upper limit measurements.

5 Remaining Issues

- Sufficient vacuum achievable inside enclosures? - needs testing ASAP
- +HV differential mode feasible - are baseline shift corrections feasible?
- Sapphire window radiopurity unknown, large samples difficult to get prior to purchase
- Radiopure potting compound needed (thermally conductive/ electrically insulating)

6 Plan for Completion of Energy Plane

At present there are some remaining design tasks and R&D activities to pursue before full scale fabrication can take place:

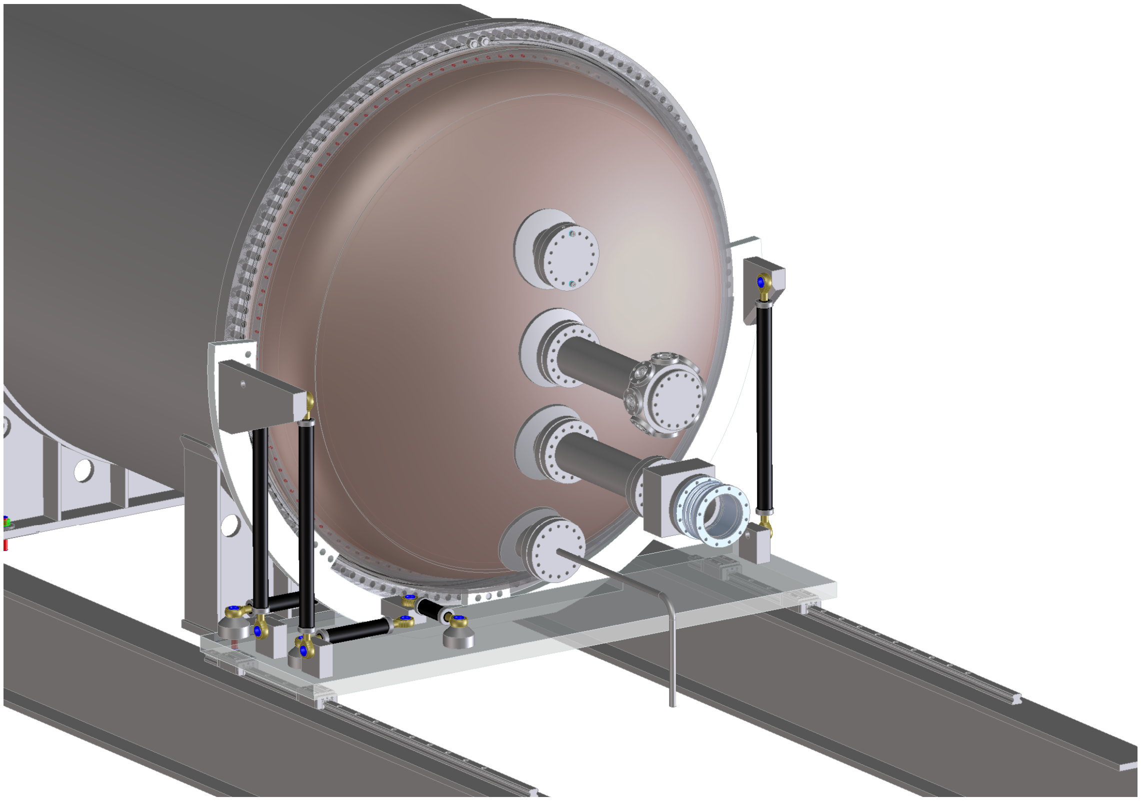

Figure 13: Hexapod Support Fixture, Attached to Torispheric Head

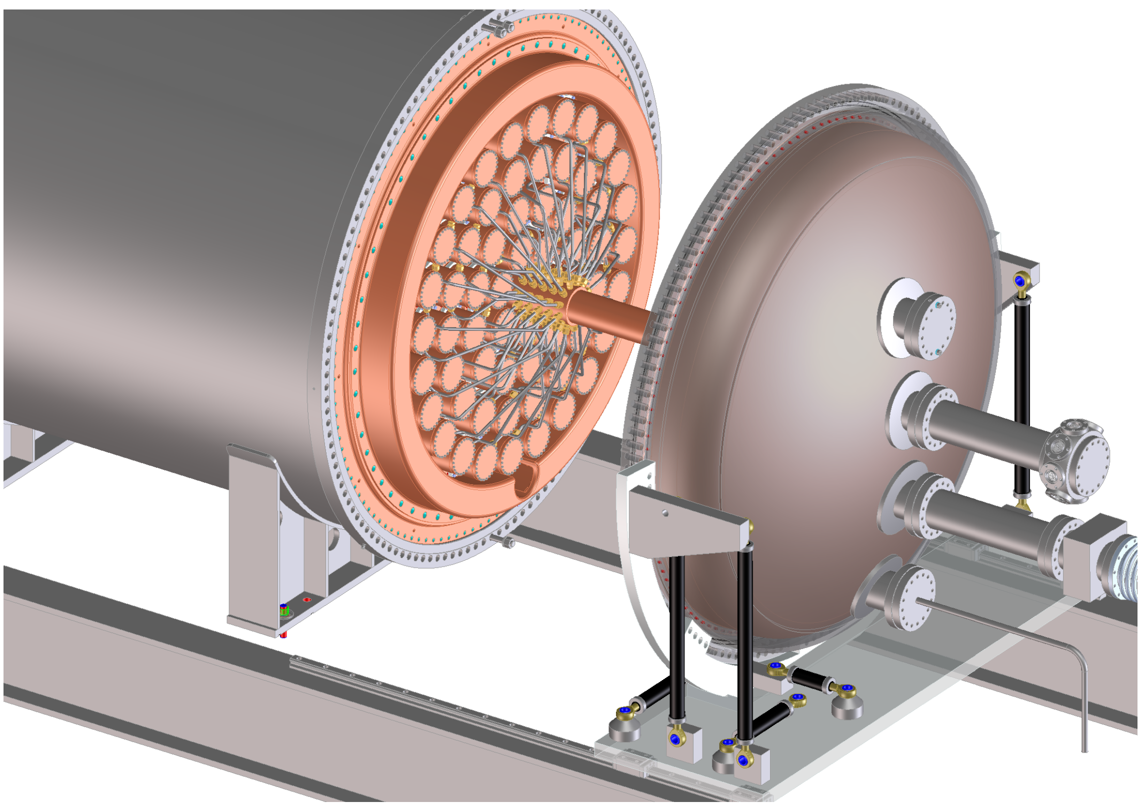

Figure 14: Hexapod Support Fixture, Attached to Torispheric Head

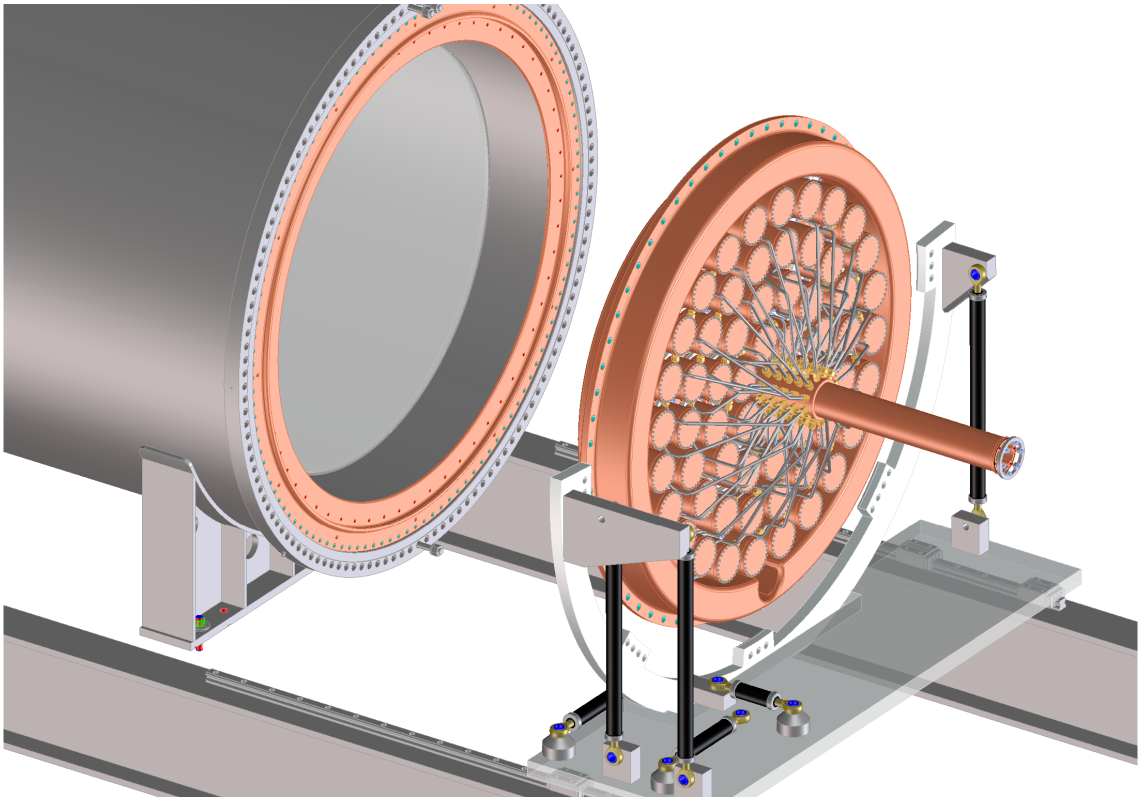

Figure 15: Hexapod Support Fixture, Attached to Carrier Plate

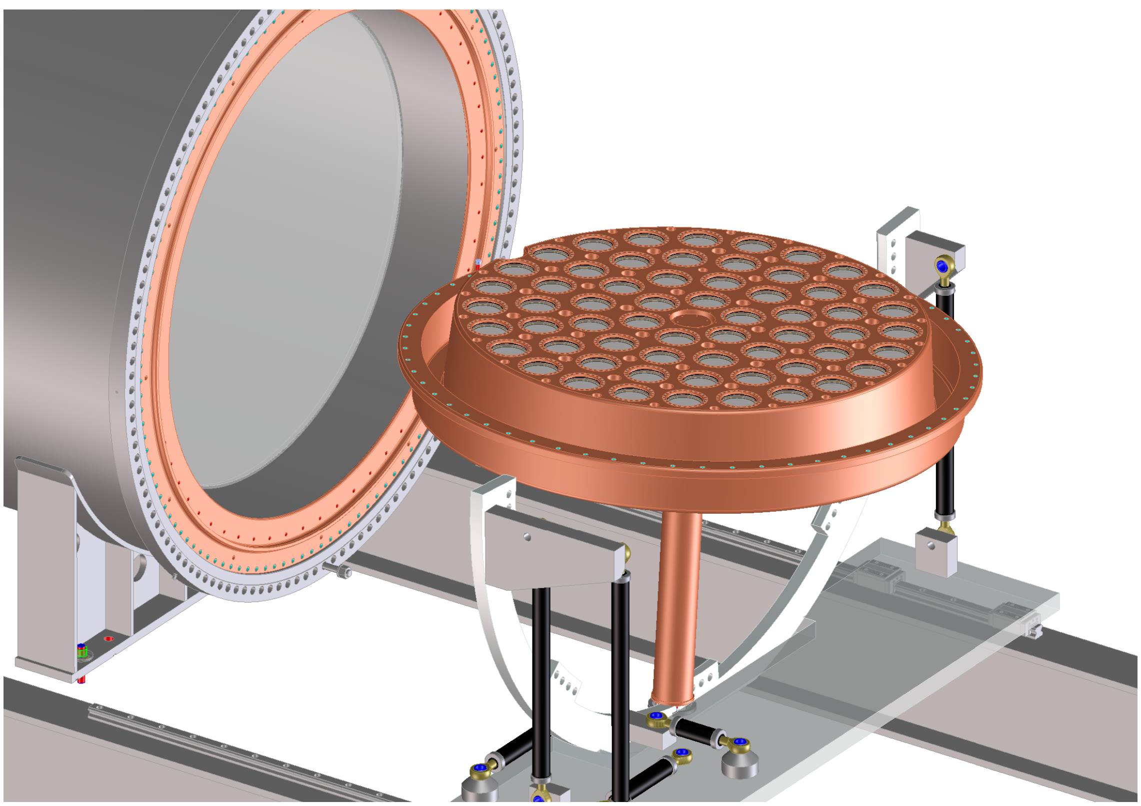

Figure 16: Hexapod Support Fixture, Attached to Carrier Plate

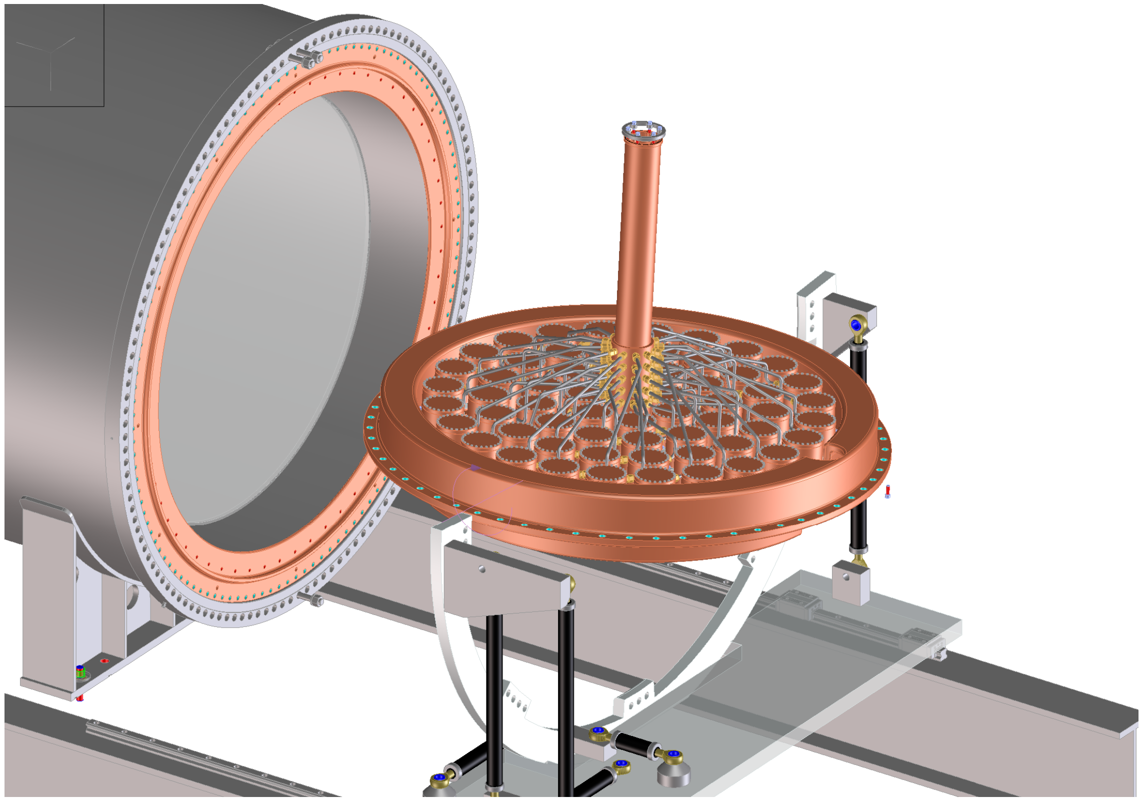

Figure 17: Hexapod Support Fixture, Attached to Carrier Plate

6.1 Remaining Design Tasks

- Central manifold - design expansion joint, integrate source and collimator, design cable termination harness at feedthroughs
- Carrier plate - Detail design - Issues: finalize HV cable location, is there to be a common ground mesh?
- Design and build window pressure test cell.
- Final base/front end/data acquisition
- Design tooling and fixtures for assembly and shipping
- Design hexapod fixture for head and carrier plate removal

6.2 R&D Activities

Progress to date :

- 3 sapphire windows purchased and received, screened for gross radiopurity: Activity ¡ 10 mBq/kg
- prototype enclosure parts are designed, fabricated, assembled and undergoing first vacuum tests

Item	unit mass	num.	mass	mat	a(U)	a(Th)	A(U)	A(Th)
	kg		kg		mBq/kg	mBq/kg	mBq	mBq
Front								
PMT		60		various	3.3 ea.	2.3 ea.	198	138
window	0.1206	60	7.2	sapphire	5	5	36.2	36.2
optical pad	0.0115	60	0.7	silicone rubber	0.162	0.492	0.1	0.3
enclosure	2.9858	60	179.1	OFE Cu	0.1	0.1	17.9	17.9
window clamp	0.1791	60	10.7	OFE Cu	0.1	0.1	1.1	1.1
pressure ring	0.0022	60	0.1	UHMWPE-30%C	6.48	12.3	0.9	1.6
O-ring	0.0007	60	0	Nitrile	120	80	5.1	3.4
window seat ring	0.0001	60	0	polyimide	120	80	0.5	0.3
window clamp screws	0.0005	1440	0.7	Si bronze	.0003	0.0007	0	0
PMT insulator	0.007	60	0.4	PEI/Ultem1000	6.48	12.3	2.7	5.1
Rear								
base PCB	0.0025	60	0.2	PTFE&Cu	0.36	0.28	0.1	0
base resistors	ea	720			0.022	0.014	15.8	10.1
base capacitors	0.0001	300	0.04	tantalum	320	410	11.5	14.8
base connectors	0.0001	720	0.1	brass	6	7	0.9	0.5
potting	0.0038	60	0.2		3000	5000	678.6	1131
cooling strap	0.0506	60	3	OFE Cu	0.1	0.1	0.3	0.3
strap screws	0.002	240	0.5	Si bronze	0.0003	0.0007	0	0
springs	0.001	180	0.2	SS	0.3	0.3	0.1	0.1
spring guide	0.025	60	1.5	PTFE	0.3	0.3	0.5	0.5
spring holder	0.05	60	3	PTFE	0.3	0.3	0.9	0.9
retaining ring	0.01	60	0.6	SS	0.3	0.3	0.2	0.2
backplate	0.6189	60	37.1	OFE Cu	0.1	0.1	3.7	3.7
backplate screws	0.0005	1440	0.7	Si bronze	0.0003	0.0007	0	0
cable	0.005	60		kapton/Cu	0.3	0.3	0	0
conduits	0.25	60	15	OFE Cu	0.1	0.1	1.5	1.5
O-ring	0.0007	60	0	Nitrile	120	80	8.5	3.4
clamp ring	0.2	60	12	SS	1	1	12	12
clamp ring screws	0.001	360	0.4	Si bronze	0.0003	0.0007	0	0
tube fittings	0.036	120	4.3	brass	6	7	56.2	30.2
System								
carrier plate		1	500	OFE Cu	0.1	0.1	50	50
central manifold		1	50	OFE Cu	0.1	0.1	5	5
interface plate		1	40	OFE Cu	0.1	0.1	4	4
copper shield		1	1500	OFE Cu	0.1	0.1	150	150
torispheric head		1	300	316Ti S	0.2	0.2	60	60
Total							1322	1682

Table 1: Activity of Energy Plane

- pressure vessel for testing enclosure is designed, fabricated and pressure tested, ready for use
- sample 41 pin feedthrough has been tested (preliminarily) for flashover as a function of

vacuum.

The following activities remain:

- Design, fabricate and test prototype base/front end for +HV operation (Nygren zener design).
- Assemble prototype enclosure, check parts for fit, function.
- Connect prototype enclosure (w/cable, no PMT) to vacuum measuring system, - use "A/B" valving to compare source pressure to inside pressure with single gauge, initial test vacuum inside.
- Install enclosure module into pressure test chamber.
- Repeat vacuum test with 15 bar various gases (Ar, Ne, He) - measure pressure, and O-ring permeation with RGA
- Install PMT/conduit/cable and test assembly for vacuum level inside enclosure.
- Final test 32 pin feedthroughs for 1750 V voltage capability, as a function of vacuum, including pin connections inside vacuum. Better pressure control is needed, possibly a different vacuum pump.
- Test PMT base/pin mockup for flashover resistance and glow discharge as a function of vacuum.
- Test various fittings (flare, VCR, Swagelok) for vacuum tightness repeatability.
- Further develop and test various heat spreader designs. Will depend on final chain current value
- Pressure test prototype windows to test pressure - test one window to failure
- Simulate buffer region e-field at window/carrier plate - in Ar@1 atm - check for corona, sparks

In addition, we have a number of Radiopurity measurements to make:

- Sapphire windows - pending successful mechanical testing, and large sample avail.
- Copper pipe samples for enclosures and central manifold
- Copper plate samples for carrier plate, and interface plate
- Copper casting samples for internal shield (unless we design with plate)
- Carbon-loaded UHMWPE for pressure rings
- Heat conducting epoxy - several measurements
- Base resistors
- base capacitors
- base PCB
- Ultem1000 insulator material
- a number of other miscellaneous measurements.

These items will be segregated into measurements at the 10 mBq/kg level and those with sufficient mass that need a second evaluation down to the 1 mBq/kg level (MAEVE/ORO detector). Each measurement takes $\tilde{1}$ wk. to perform.

7 Cost and Schedule

Name	Start	Finish
EDI (Engineering, Design, Integration)	**4/18/2012**	**10/16/2012**
Integration	4/18/2012	9/4/2012
Enclosure Final Design	5/16/2012	6/8/2012
Carrier plate design	7/13/2012	7/26/2012
InterfacePlate Design	7/26/2012	8/1/2012
Central manifold design	8/21/2012	8/31/2012
Internal Shield Design	9/26/2012	10/3/2012
Base Design	4/18/2012	5/24/2012
Heatsink Design	8/7/2012	8/10/2012
Window pressure test chamber design	4/18/2012	5/22/2012
Hexapod Handling Fxture design	9/5/2012	9/20/2012
Assembly Fixturing and Tooling design	7/26/2012	8/21/2012
ICMOL coat chamber modification	5/16/2012	5/18/2012
Window shipping container	7/31/2012	8/2/2012
Energy plane shipping container	10/9/2012	10/16/2012
prototyping	**4/18/2012**	**6/29/2012**
base prototyping	4/18/2012	4/24/2012
first enclosure assembly	6/27/2012	6/29/2012
initial vacuum test, no PMT	4/20/2012	4/25/2012
install into pressure chamber	4/26/2012	4/27/2012
vacuum/pressure test	5/1/2012	5/3/2012
install PMT- check optical coupling	5/10/2012	5/15/2012
window pressure test chamber fab	5/23/2012	5/25/2012
field simulator design&fab	4/18/2012	5/30/2012
HV test	5/31/2012	6/5/2012
base potting mold, design&fab	5/25/2012	5/29/2012
Mechanical Fabrications	**4/18/2012**	**10/26/2012**
Radiopurity Measurements	4/18/2012	8/23/2012
sapphire windows	4/18/2012	5/9/2012
optical pads	5/10/2012	5/14/2012
copper pipe	5/15/2012	6/5/2012
copper plate	6/6/2012	6/27/2012
polyethylene, field cage 1	6/28/2012	7/19/2012
polyethylene, fied cage 2	7/20/2012	8/10/2012
heat conducting epoxy 1	7/20/2012	7/24/2012
heat conducting epoxy 2	7/25/2012	7/27/2012
heat conducting epoxy 3	7/30/2012	8/1/2012
heat conducting epoxy 4	8/2/2012	8/23/2012
heat sinks fab	8/10/2012	8/15/2012
sapphire window procurement	5/4/2012	8/23/2012
Enclosures fab	6/11/2012	7/12/2012
Carrier plate fab	7/26/2012	8/16/2012
Interface plate fab	8/16/2012	8/23/2012
Central Manifold fab	9/3/2012	9/7/2012
shield plate (ICS) fab	10/4/2012	10/24/2012
conduits fab	9/4/2012	9/12/2012
hexapod fab	9/21/2012	10/4/2012
window shippping container	8/2/2012	8/7/2012
energy plane shipping container	10/17/2012	10/26/2012
Electrical Fabrications	**5/25/2012**	**7/19/2012**
base fab	5/25/2012	6/14/2012
front end amplifiers fab	5/31/2012	7/5/2012
power supplies fab	7/6/2012	7/12/2012
data aquisition fab	7/13/2012	7/19/2012
Assembly	**4/18/2012**	**1/1/2013**
pot heatsinks to bases	8/15/2012	8/22/2012
solder bases to PMTs	8/22/2012	8/27/2012
pressure test windows	8/24/2012	8/30/2012
package and ship windows to ICMOL	8/31/2012	9/3/2012
ITO/TPB coat @ ICMOL	9/4/2012	9/24/2012
package and ship windows to LBNL	9/25/2012	9/25/2012
assemble windows into cans	9/26/2012	10/2/2012
assemble PMT's into cans	10/3/2012	10/5/2012
test PMT Modules	10/8/2012	10/19/2012
assemble PMT modules to carrier plate	10/22/2012	10/26/2012
assemble central manifold to carrier plate	10/29/2012	10/31/2012
assemble conduit/cable assemblies	11/1/2012	11/21/2012
test energy plane (vac, elect.)	11/22/2012	12/18/2012
assemble energy plane into shipping contai	12/19/2012	12/26/2012
ship to Canfranc	12/27/2012	1/1/2013

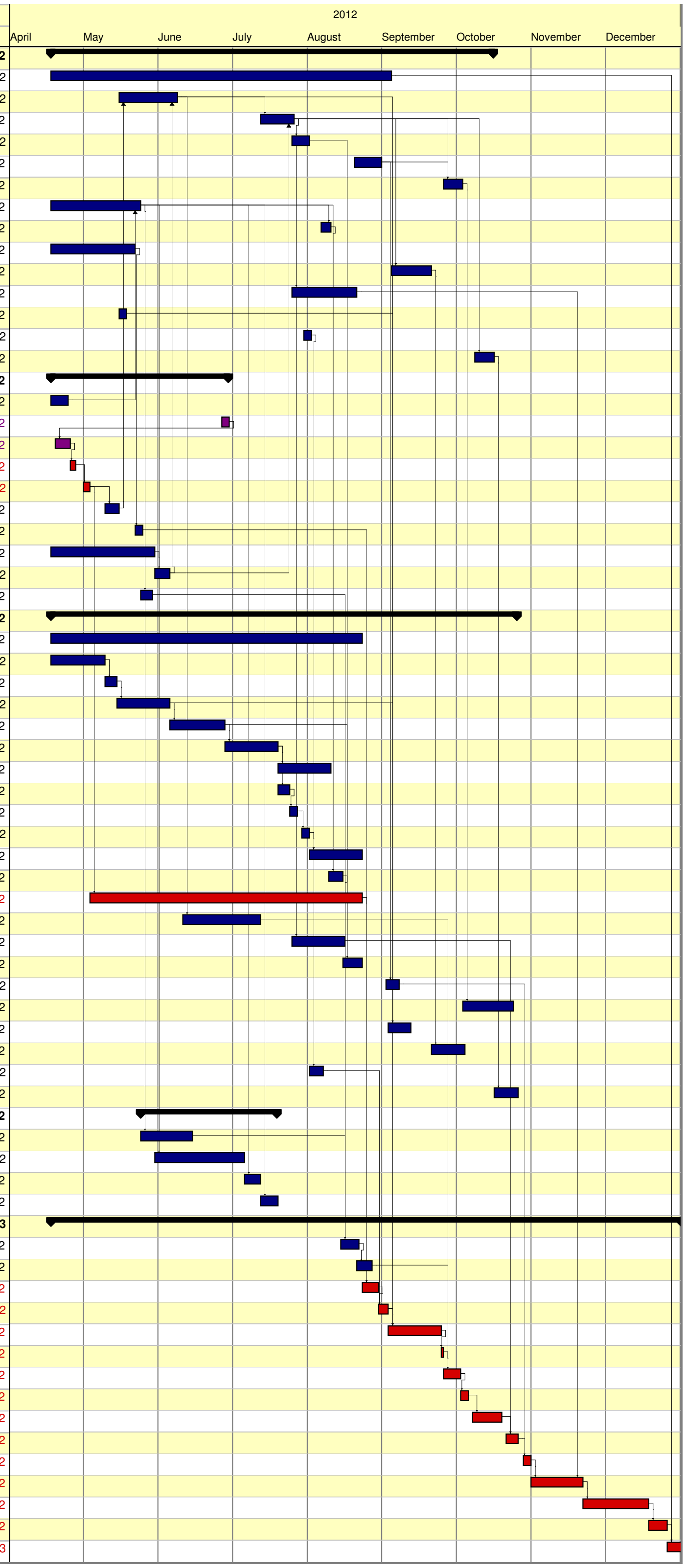

Figure 18: Energy Plane Schedule, Preliminary

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8 Appendix

8.1 Test pressure ratio

LEFM defines a material quantity called stress intensity K that is a function of material, applied stress σ and crack length a. When this quantity reaches a critical value K_{Ic} (from either increased crack length, or increased stress) a previously stable, but slow growing crack of associated length a_{cr} will undergo rapid uncontrolled propagation. Single crystal sapphire (C-plane parallel to window plane; strongest orientation) has a well measured K_{Ic} [5]. In addition single crystal sapphire also has a threshold stress intensity K_{TH} where crack growth is so slow as to be unmeasurable [4]; this is our desired maximum operating point. The formula for stress intensity is:

$$K = Y\sigma\sqrt{\pi a}$$

Critical stress intensity, in air, from [5]:

$$K_{Ic} = 2.5 \text{ MPa}\sqrt{m}$$

Threshold stress intensity [4]:

$$K_{TH} = 1.64 \text{ MPa}\sqrt{m}$$

Y is a geometric factor which will cancel out below. We want the (maximum) critical stress intensity at the test pressure to fall off to the threshold stress intensity at our operating pressure, so our desired test-to-actual pressure ratio R_p is simply:

$$R_p = \frac{K_{Ic}}{K_{TH}} = \frac{2.5}{1.64} = 1.52$$

8.2 Minimum Window Thickness

Typical strength testing results, where specimens are stressed to failure (short term loading), can be characterized by a two-parameter Weibull distribution, where the probability of survival (for any successive identical test specimen) as a function of stress σ is given.

$$P_s = e^{-\left(\frac{\sigma}{\sigma_0}\right)^m}$$

The two parameters refer to the quantities σ_0 which is the called the characteristic stress and represents the stress at which 63% of specimens will fail, and the exponent m, which is called the Weibull modulus and is a measure of the stress spread, from low to high failure (or survival) probability; a low number indicates a wide range of stresses over which there are significant failure/survival probabilities, which is characteristic of brittle materials where there is a random distribution of surface or volume flaws which are difficult to eliminate. A high number is characteristic of ductile metals (>10), and a modulus of 1 indicates completely random failure. The modulus may even be negative which is an indication of infant mortality failure modes.

The characteristic stress is only applicable to parts that are the same size, surface condition, and loading distribution of the test specimen. Furthermore it is often normalized to a standard test area and stress distribution, which is typically a circular 1 cm^2 area loaded in a ring-on-ring fixture which produces a uniform biaxial bending stress distribution. To account for the difference in area between the test specimen an actual part and the different stress distribution (pressure loading produces a nonuniform stress) the following formula results:

$$P_s = e^{-k\left(\frac{A}{A_0}\right)^m\left(\frac{\sigma}{\sigma_0}\right)^m}$$

The factor k is a function of m and represents a weighting factor derived from integrating the probability function over the stress distribution and normalizing it to the uniform stress distribution of the characteristic strength. The area ratio $\frac{A}{A_0}$ relates actual stressed area to characteristic area.

Klein [3] gives a Weibull modulus $m = 3.4$ and characteristic strength $\sigma_0 = 975$ MPa for a 1 cm^2 uniform biaxial stress, for c-plane oriented specimens of 60/40 scratch/dig polish specification. Salem [5] gives a formula for an effective area, as a function of m from which $k(m = 3.4) = .332$ is readily computed, and is applied to the area ratio of actual to characteristic areas, A_w (= 45 for our window size). We then solve for a maximum stress at the test pressure of:

$$\sigma_t = \sigma_0\left(\frac{ln(P_s)}{-kA_w}\right)^{\frac{1}{m}} = 975 \text{ MPa}\left(\frac{ln(.95)}{-.332 * 45}\right)^{\frac{1}{3.4}} = 186 \text{ MPa}$$

and our design stress for actual pressure $p = 15$ bar is:

$$\sigma_d = \frac{\sigma_t}{R_p} = \frac{186 \text{ MPa}}{1.52} = 120 \text{ MPa}$$

and a resulting window minimum thickness, using a simple formula for a circular plate loaded in bending, with simple edge supports [6](table 24, case 10a), ($\nu = .29$ is Poisson's ratio for sapphire) is then:

$$t = \sqrt{\frac{3}{8}(3+\nu)\frac{p}{\sigma_d}r^2} = \sqrt{\frac{3}{8}(3+0.29)\frac{1.5 \text{ MPa}}{120 \text{ MPa}}r^2} = 4.9mm$$